Planning and Control of UGVs in a Dynamic Environment: A Practical Framework with Experiments

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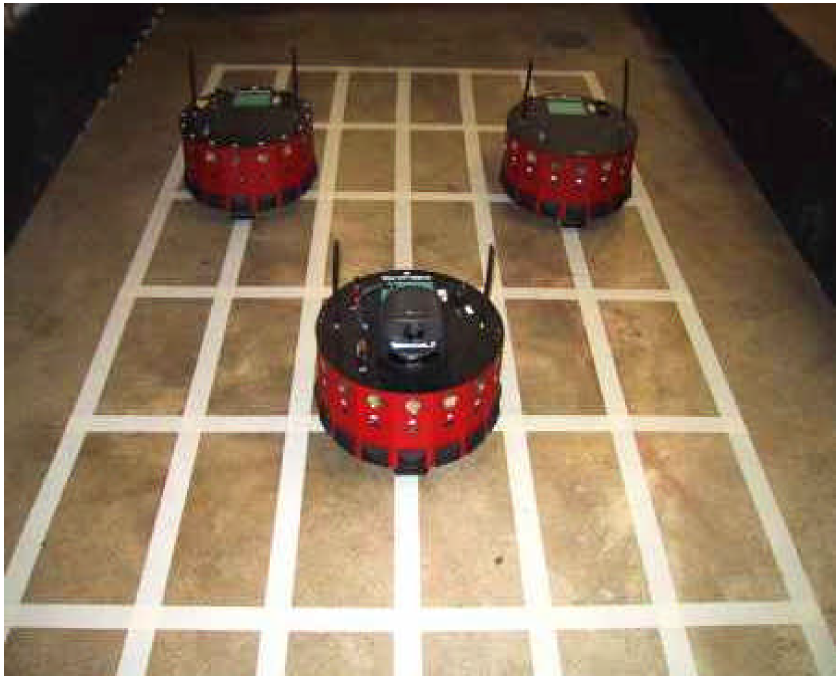
INTRODUCTION



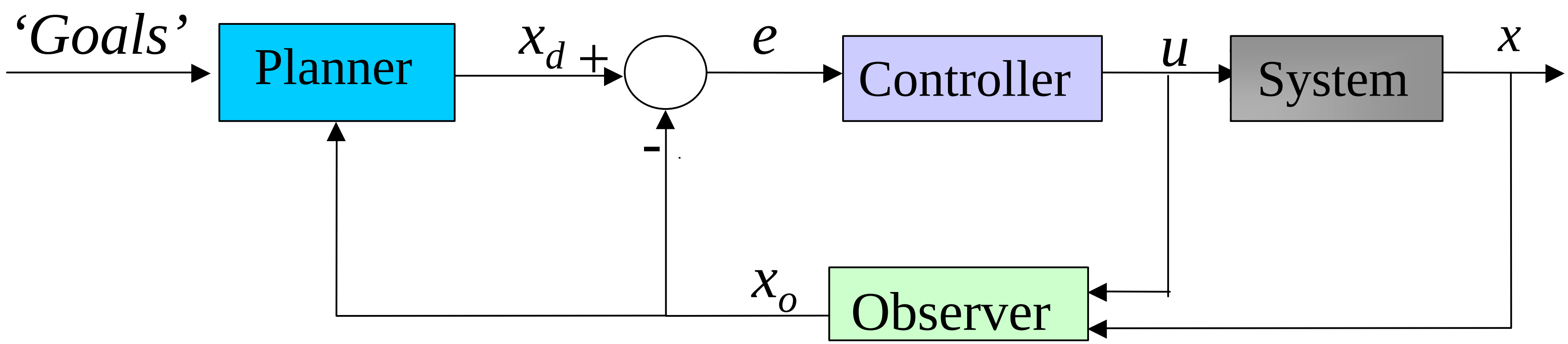
Goal:

Planning and control of formations of multiple unmanned ground vehicles to traverse between goal points in a dynamic environment

INTRODUCTION

$$\dot{x} = F(x,u)$$

$$x \in \Re^n, u \in \Re^m$$



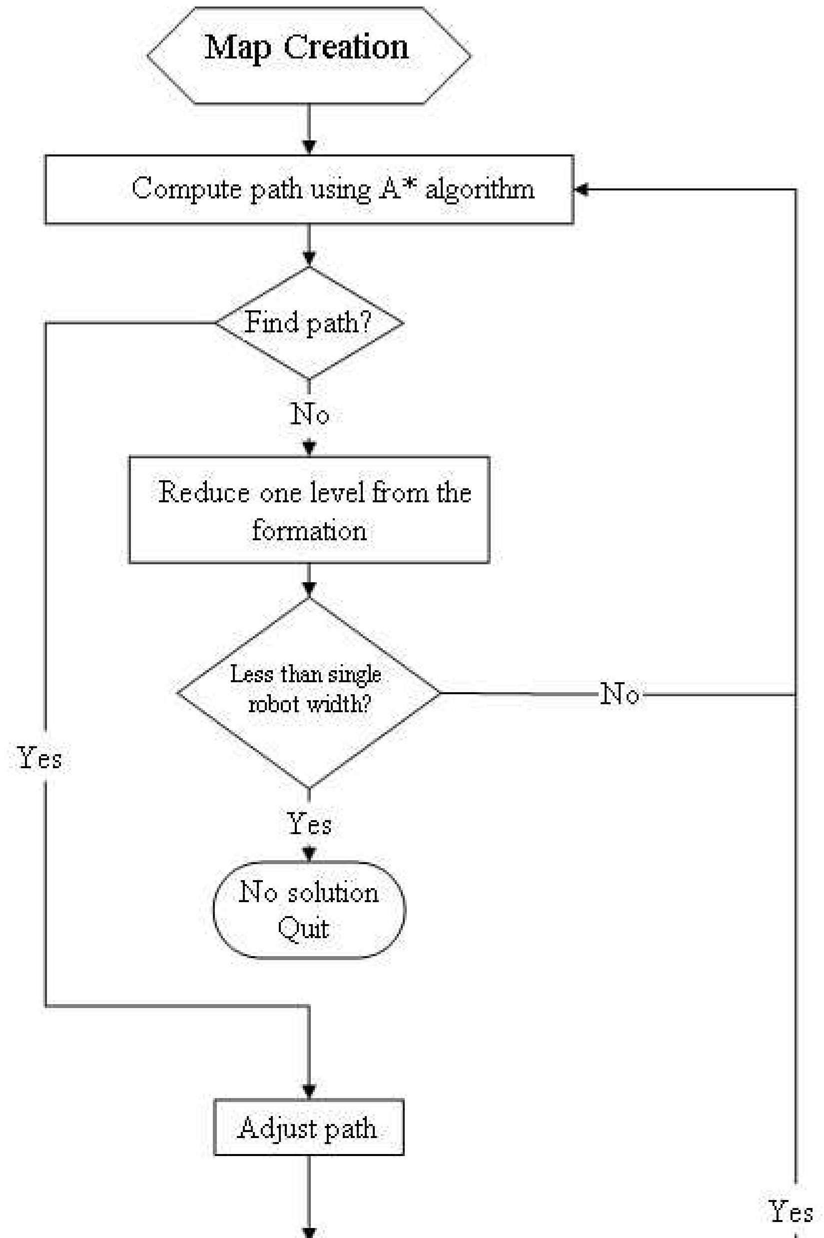
OUTLINE

- I. Flowchart
- II. Dijkstra Search – Finding via points
- III. Trajectory Generation and Tracking Controller
- IV. Laboratory Experiments
- V. Formations of UGVs with Trailer
- VI. Conclusions

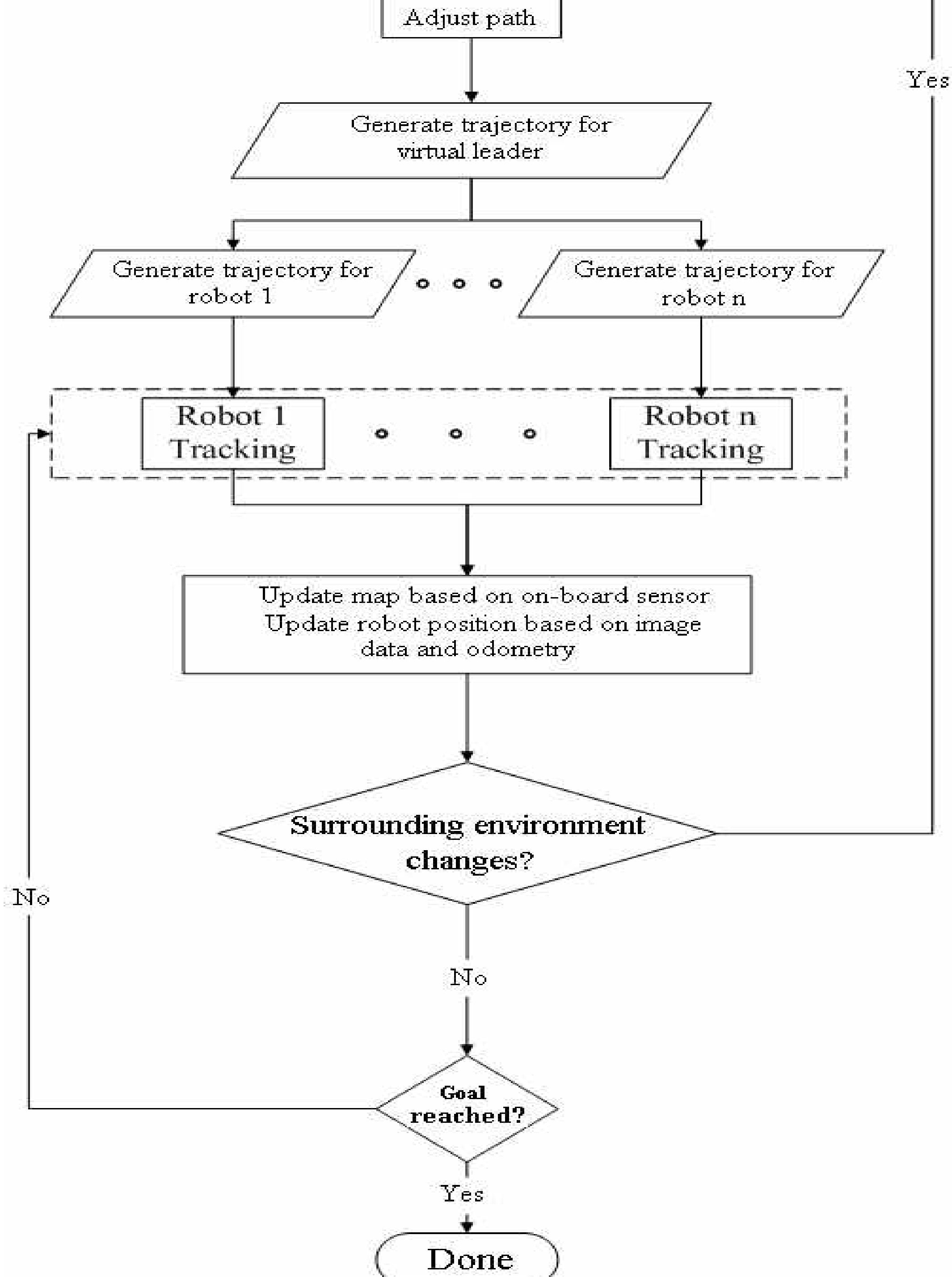
Assumptions

- Robots have on-board sensors, computing, and communication
- Robots change formations recursively to avoid obstacles
- Robot dynamics are accounted during trajectory planning
- Tracking controllers keep the error bounded
- Environment is slowly varying
- UGV's are differentially driven robots with speed commands

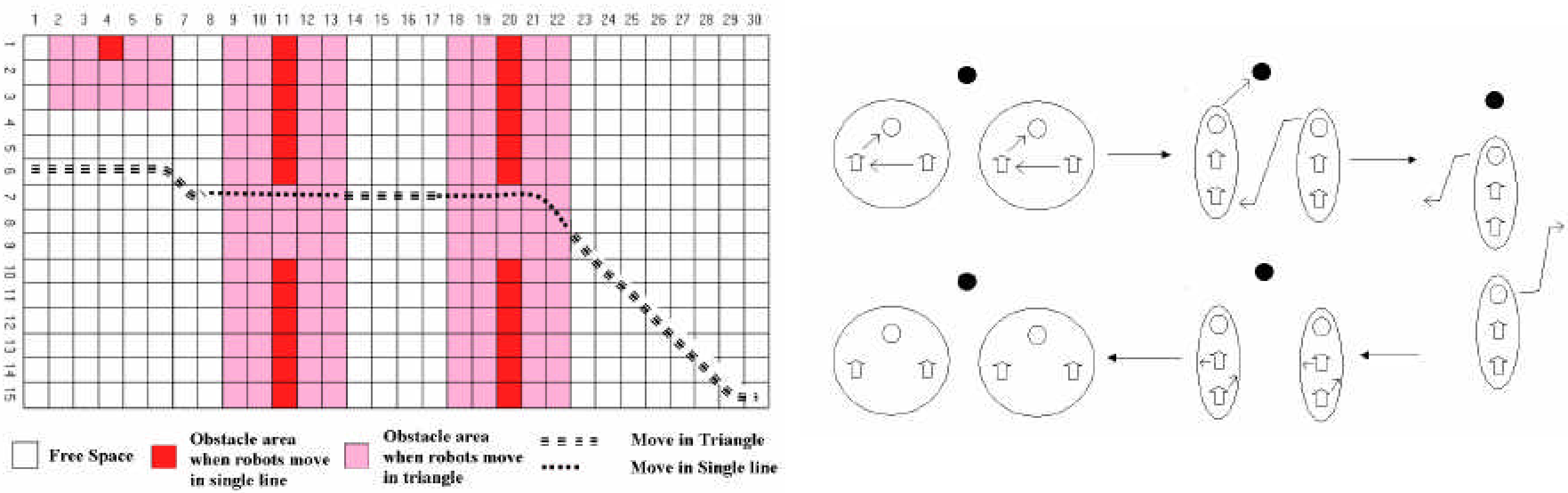
Framework



Map Creation
Compute path using A* algorithm
Find path?
No
Reduce one level from the formation
Less than single robot width?
No
Yes
Yes
No solution Quit
Adjust path
Yes

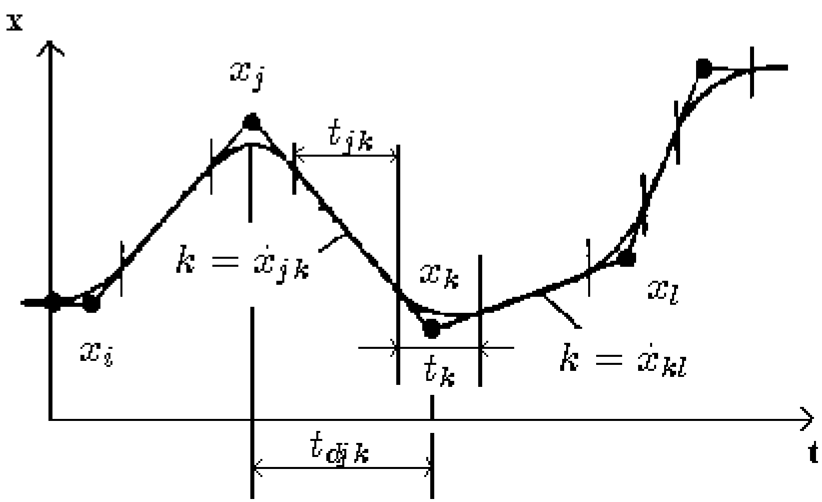

Adjust path
Yes
Generate trajectory for virtual leader
Generate trajectory for robot 1
Generate trajectory for robot n
Robot 1 Tracking
Robot n Tracking
Update map based on on-board sensor
Update robot position based on image data and odometry
Surrounding environment changes?
No
No
Goal reached?
Yes
Done

Framework

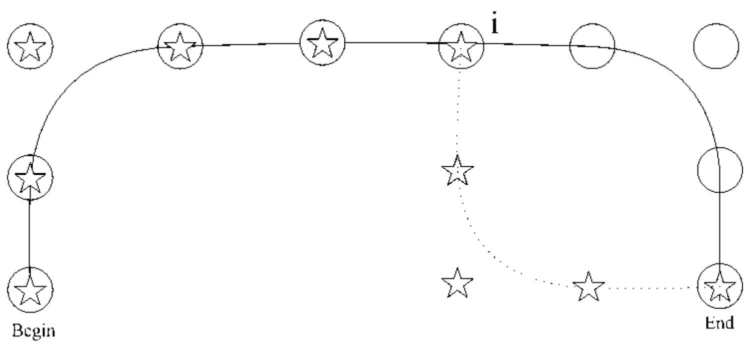


An illustration of a formation change from a tree to a line to a tree.

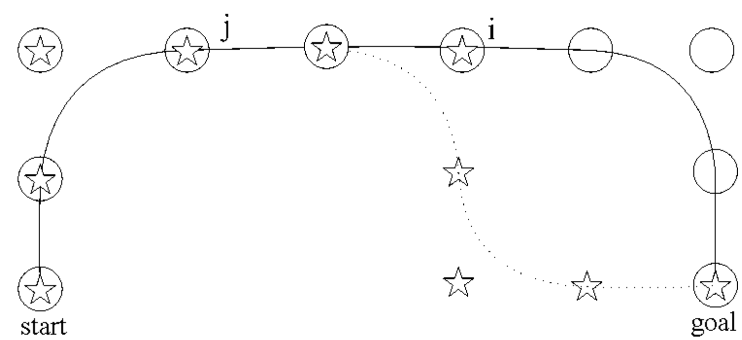
Smooth Trajectory from Via Points



- Interpolating functions
- Use of cubic Splines



Sharp Turning



Smooth Turning

Tracking Controller: Use of Lyapunov functions

Vehicle Model:

$$\dot{x}_i = u_{1i} cos\theta_i$$
$$\dot{y}_i = u_{1i} sin\theta_i$$
$$\dot{\theta}_i = u_{2i}$$

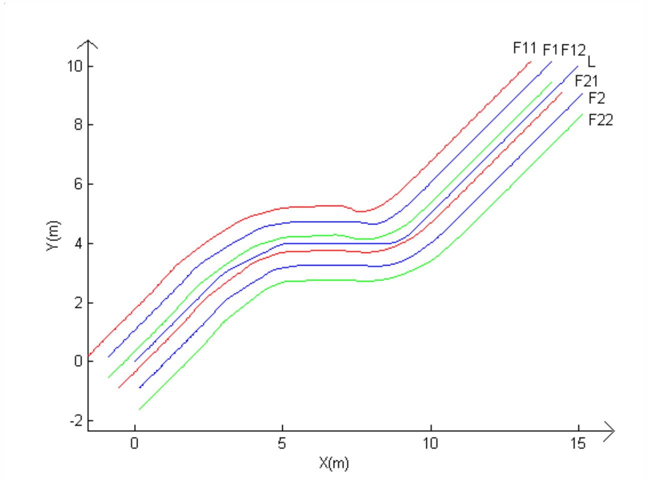
Error Model:

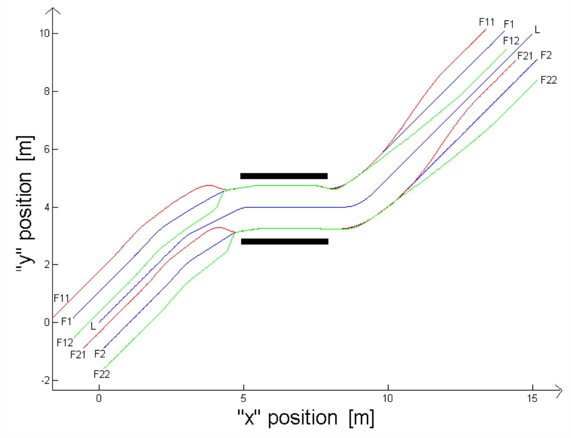
$$x_{ei}(t) = x_{ri}(t) - x_i(t)$$
$$y_{ei}(t) = y_{ri}(t) - y_i(t)$$
$$\theta_{ei}(t) = \theta_{di}(t) - \theta_i(t)$$

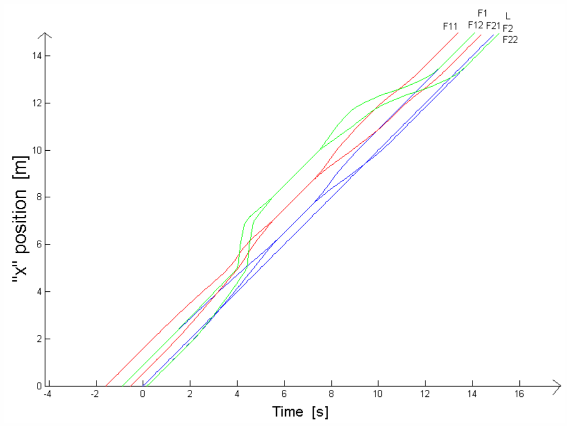
Asymptotically Stable Control Law:

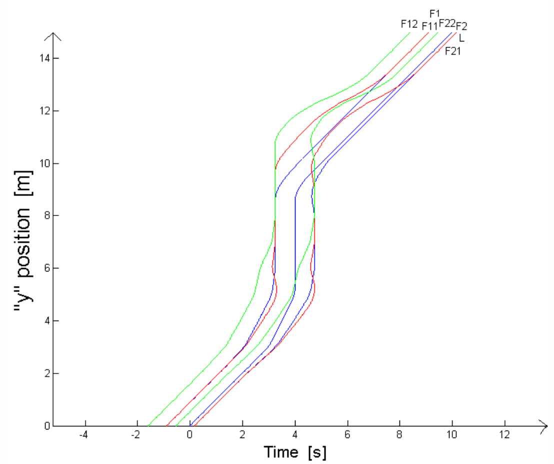
$$u_{1i} = \frac{x_{ei}\dot{x}_{ri} + y_{ei}\dot{y}_{ri}}{x_{ei} cos\theta_i + y_{ei} sin\theta_i} + k_{1i}(x_{ei} cos\theta_i + y_{ei} sin\theta_i)$$
$$u_{2i} = \frac{x_{ei}(\dot{y}_{ri} - u_{1i} sin\theta_i) - y_{ei}(\dot{x}_{ri} - u_{1i} cos\theta_i)}{{x_{ei}}^2 + {y_{ei}}^2}$$

Simulation: Trajectory Generation / Tracking

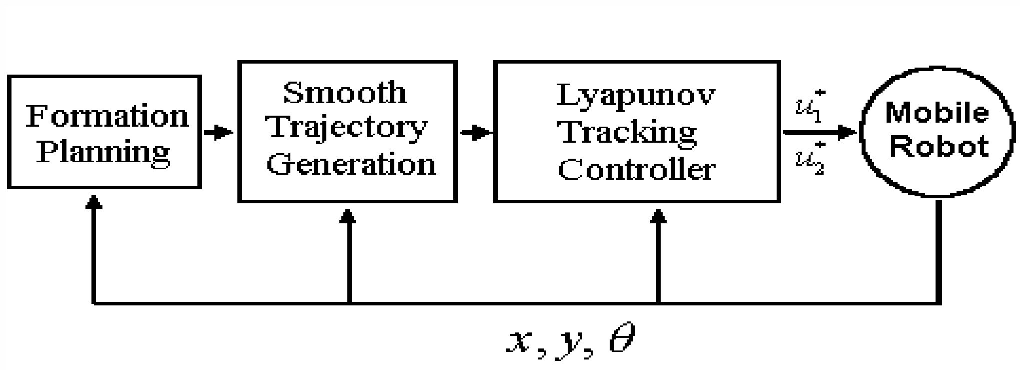


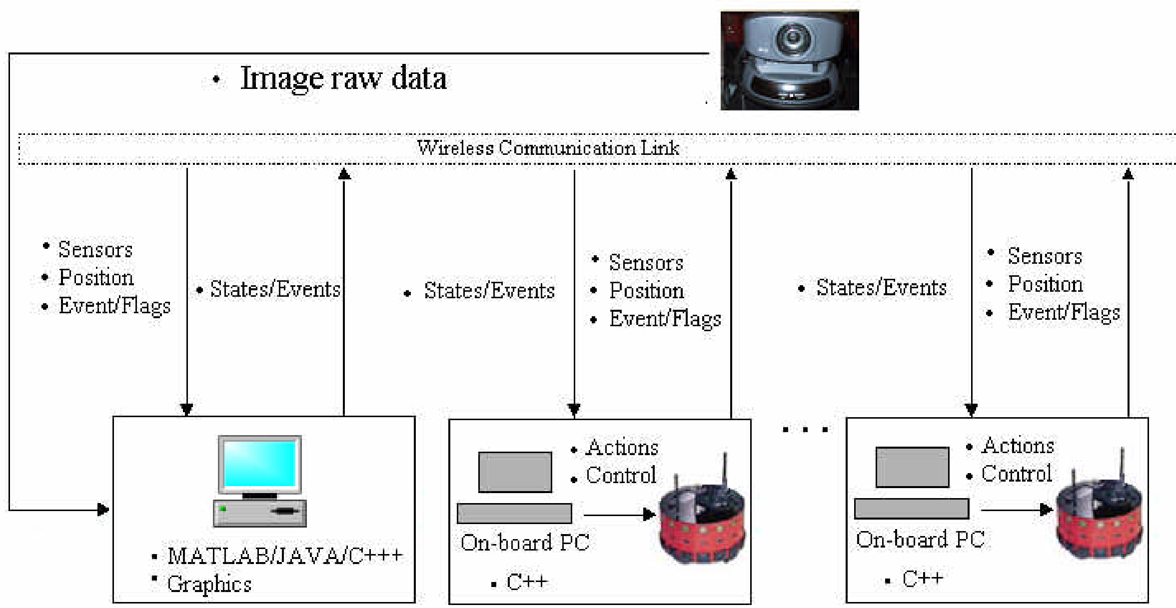




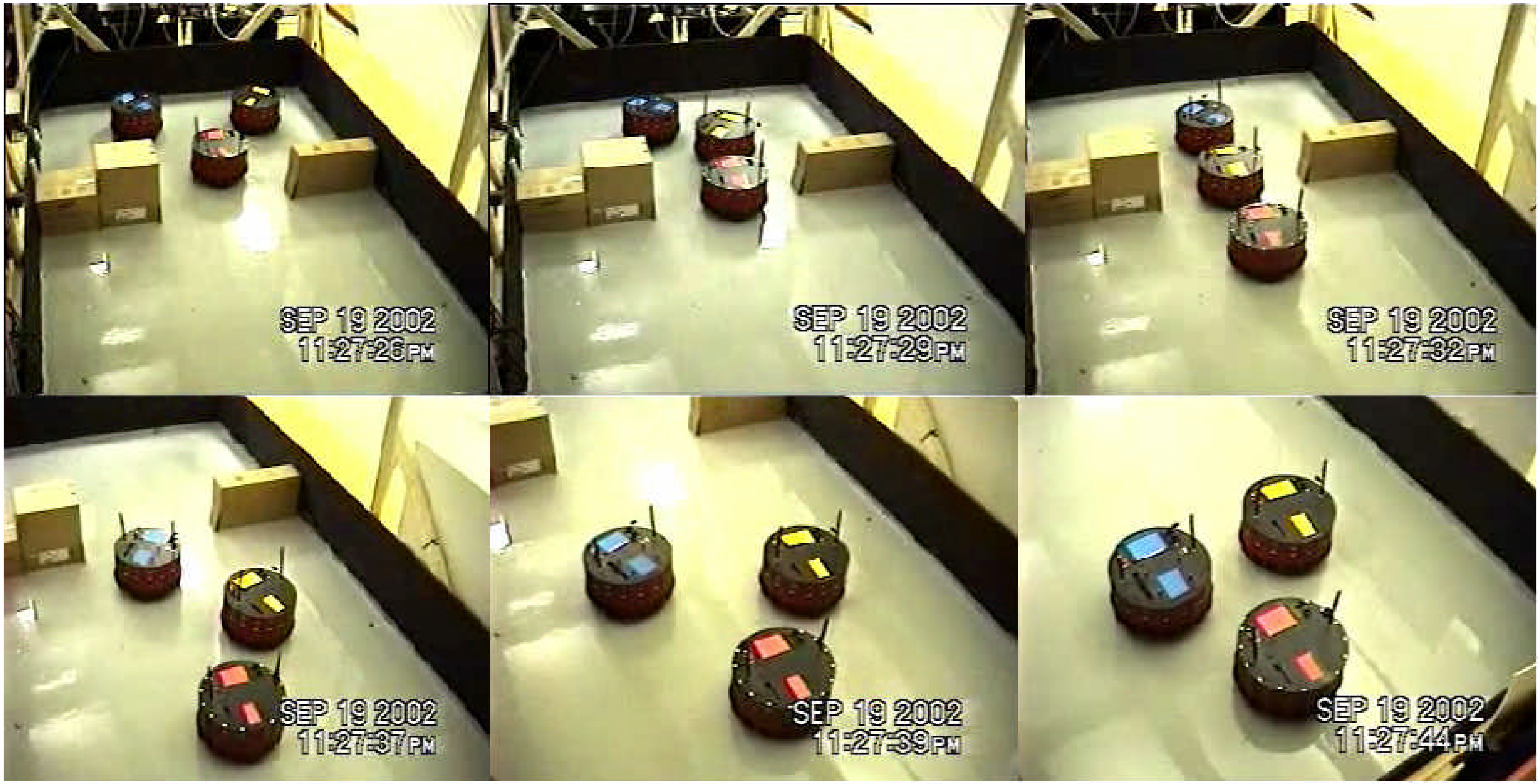


Laboratory Experiments



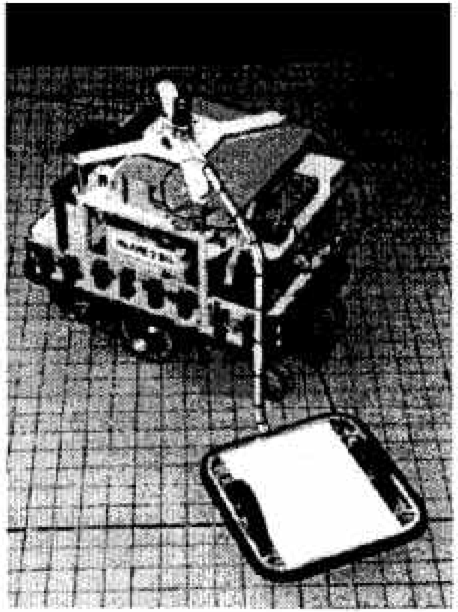


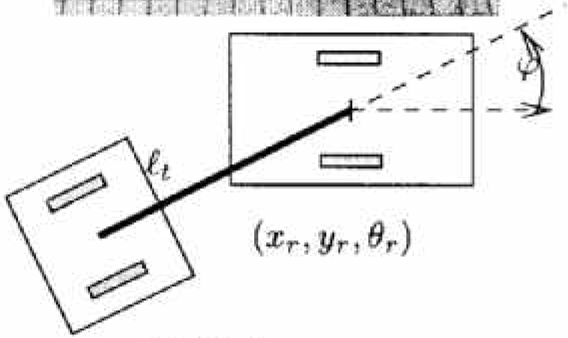
Laboratory Experiments: Snapshots (Movie Follows)



Laboratory Experiments

Control of UGVs with Trailers



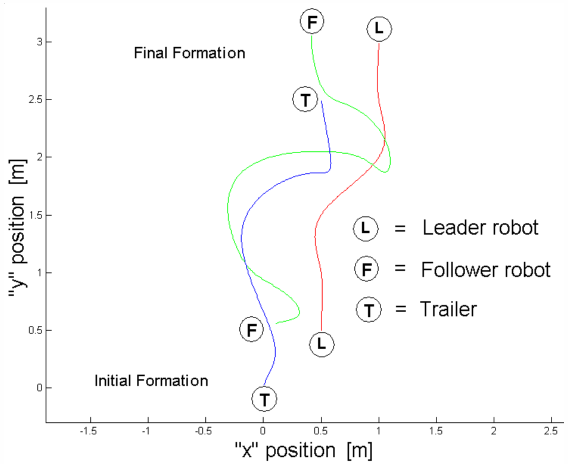


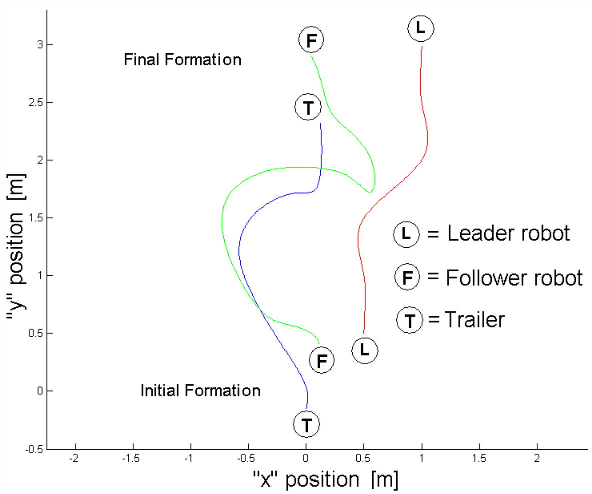
- Vehicle Models

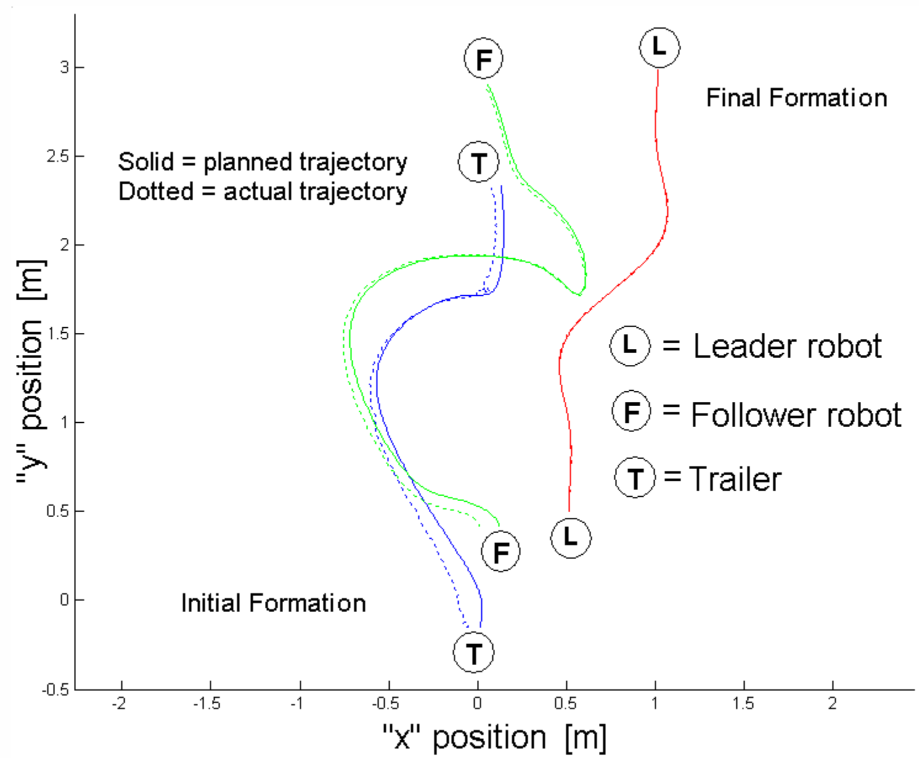
$$
\begin{aligned}
\dot{x}_r &= v_r \cos\theta_r \\
\dot{y}_r &= v_r \sin\theta_r \\
\dot{\theta}_r &= \omega_r \\
\dot{\varphi} &= -\frac{v_r}{l_t}\sin(\varphi) - \frac{l_r\omega_r}{l_t}\cos(\varphi) - \omega_r
\end{aligned}
$$

- Planning and control methods can be simply extended

Simulation of Formations of UGVs with Trailer







Experiment with a UGV/Trailer: (Motivation from crop harvesting)

Conclusions and Planned Work

- A Practical framework is in place for trajectory planning and control of single and groups of vehicles in static and dynamic environments.

- This framework has been tested in laboratory test environment.

- Current plan is to implement this methodology on NIST mobile vehicle platforms and study issues of transfer of this technology for use in industrial environment.